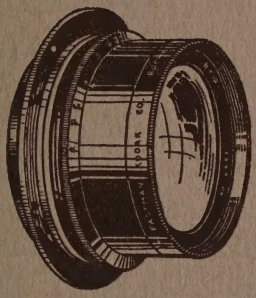
About

Lenses



Eastman Kodak Company
Rochester, N. Y.

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About

Lenses

Eastman Kodak Company
Rochester, N. Y.
1929

First Stages in Lens Making

Optical glass from which Kodak Anastigmat lenses are made is delivered in slabs such as those illustrated at the top of this page. The large slab, on the left, is ten inches high.

After passing exhaustive tests to prove its chemical homogeneity and to determine its index of refraction, each slab is cut into sticks by diamond-pointed saws. These glasses, because of the methods necessary for their making, always contain many fine bubbles of air. These are unavoidable. In fact, their absence would cause an expert to doubt the genuineness of the lens. Fortunately, they do not affect the photographic ability of the lens.

The sticks are then sawed into cubes which are softened in gas furnaces and pressed into discs. The discs are annealed by gradual cooling in an electric oven. Then they must pass tests for flaws and strain before they are admitted to the grinding rooms. There, in a long series of operations and inspections, they are ground and polished to within 1/30,000 of an inch of perfection.

ABOUT LENSES

CHAPTER I

How a Lens Forms an Image

In order to take a photograph we use a lens which forms an image of the object we want to photograph upon the film.

The simplest lens which we could use would be a small hole. If we take a sheet of cardboard and make a hole in it with a pin, and then, in a darkened room, hold the cardboard between a sheet of white paper and an electric lamp, we shall see on the paper an image of the lamp filament.

The diagram shows how this image is produced. A ray of light from each portion of the filament passes through the pinhole and forms a spot of light on the paper, and all these spots joining together form the image of the filament.

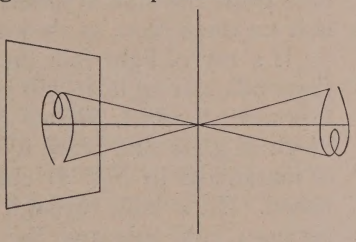


Fig. 1

If we take the lens out of a camera and replace it by a thin piece of metal pierced with a hole made by a needle (a No. 10 sewing needle is about right, and the edges of the hole must be beveled off so that they are sharp), then we can take excellent photographs by giving sufficient exposure.

If the pinhole is about six inches from the film, then an exposure of about one minute for an outdoor picture on film will be required. It is necessary, of course, to make a well fitting cap for the lens aperture so that no light will get in except through the pinhole, and also to make a cover for the pinhole to act as a shutter for exposing.

But if a pinhole were the only means of forming an image it is very improbable that photography would ever have been developed, since the exposures are so long in consequence of the small amount of light which can pass through the pinhole.

In order to get more light, we could try making the pinhole larger, but the effect of this is to make the image very indistinct, and even the smallest efficient pinhole can not give as sharp an image as a good lens.

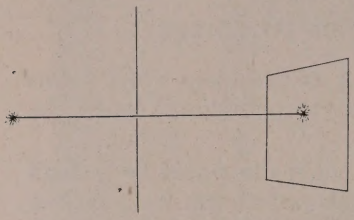


Fig. 2

Suppose we have a small pinhole forming an image of a star, as shown in Fig. 2. If we make the hole larger, we shall get a round, spreading beam of light and no longer get a sharp image. (Fig. 3.)

What we need, if we are to use the large hole, is some means of bending the light so that all the light reaching the hole from the star is joined again in a sharp image of the star on the screen, as shown in Fig. 4.

If a ray of light falls on a piece of glass so that it is not perpendicular to it, it will be bent. There is an interesting experiment which shows this very well. Take a thick block of glass and place it so that it touches a pin (which is marked B in Fig. 5) and stick another pin (A) in the board. Now look through the glass and stick a pin (D) between your eye and the glass, and in the same line of

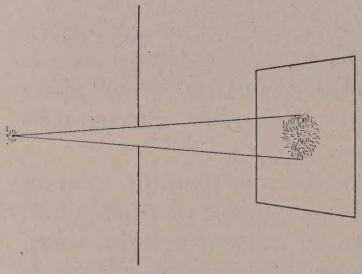


Fig. 3

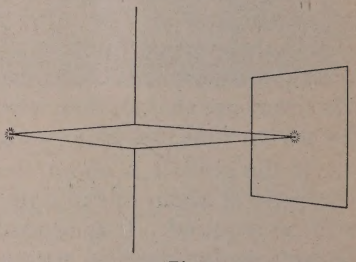


Fig. 4

sight as A and B, and lastly another pin (C) touching the glass and in the same line of sight as the other three.

Take away the glass and join up the pinholes with pencil lines. You will find that the line DC is parallel to the line AB but is not in the same line; that is, *the ray of light marked by the line AB was bent when it entered the glass* and then bent back again when it left it. This experiment shows

that we can bend light by means of glass.

If we take a triangular piece of glass (called a prism) we can bend a ray when it enters the glass and also again when it leaves the glass. (Fig. 7.) And a lens is really

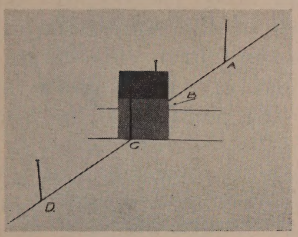


Fig. 5

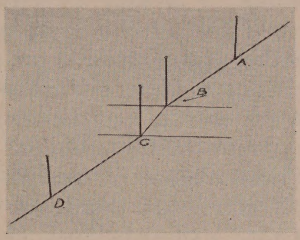


Fig. 6

two prisms stuck together base to base (Fig. 8). So that if we put a lens in the hole with which we want to form an image, we can now do what we wanted to, namely, make all the rays from the star come together again in the image

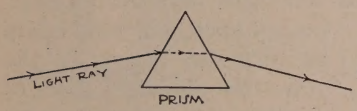


Fig. 7

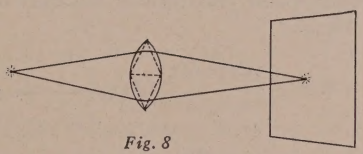


Fig. 8

of the star. This is the purpose of our camera lenses, to form an image as sharp as that given by the smallest pinhole and yet much brighter than any pinhole could give.

CHAPTER II

Focal Length

Should we place a pinhole, instead of a lens, in the front-board of our camera, we could use the same size of pinhole for making all sizes of pictures, because the image formed by a pinhole is always of the same sharpness, whether the pinhole is far from the film or close to it. If we want a large picture we must, of course, use a large camera with a long bellows, so the pinhole will be a long way from the film, while if we want a small picture we shall only need a small camera with a short bellows, so that the pinhole will be near the film. But if, instead of a pinhole, we use a lens, we shall find that the lens must be placed at a certain distance from the film (depending upon its focal length and its distance from the object photographed) in order to obtain a sharp picture. If it is placed at any other distance from the film, the picture will be all blurred. The reason for this is that a photographic lens bends the rays of light that pass through it so that all the light rays from a star, for instance, will meet again to form an image of the star. By placing a sheet of cardboard at the position where the rays of light meet, the image of the star will be sharp, but if we put the card either nearer to or farther from the lens, the image will be blurred into a circle of light. The distance at which the lens must be placed from the film to give a sharp image of a distant object represents the "focal length" of the lens.

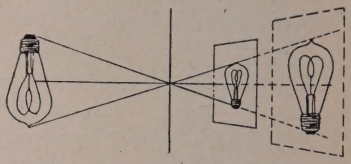


Fig. 9

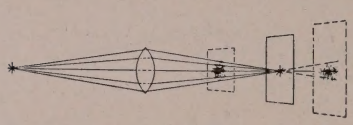


Fig. 10

The longer the focal length of a lens the larger the image, and the shorter the focal length the smaller the image. Suppose we photograph a tree and place the camera at such a distance from the tree that with a lens of three inches

focal length we obtain a picture in which the image of the tree is one inch long.

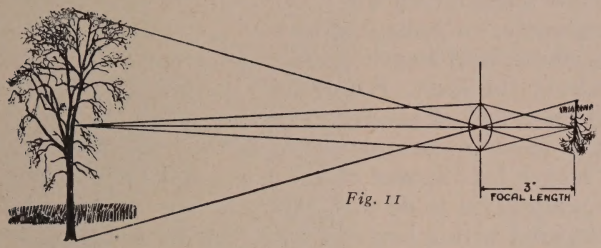


Fig. 11

Now if, with the camera at the same distance from the tree, we had used a six-inch lens instead of the three-inch lens, which means that instead of the lens being three inches from the film it would be six inches from it, then the image of the tree would be two inches long instead of one inch long in the picture. If we were using the same size film with both lenses, of course we would not be able to include as much of the subject we were photographing in the field of view of the picture made with the six-inch lens

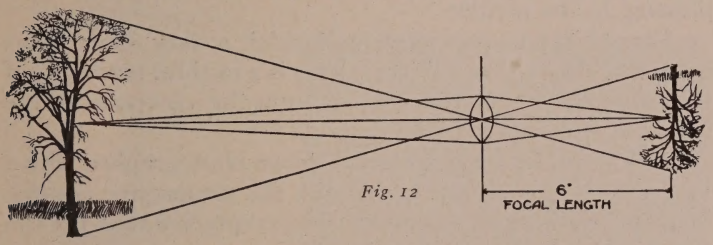


Fig. 12

as we would obtain with the three-inch lens, because with the three-inch lens the tree would be, say, a quarter of the length of the film, while with the six-inch lens it would be half the length of the film. In other words, the three-inch lens would give us a smaller image, while the six-inch lens would give us a larger image of the tree.

The longer the focal length of a lens, the less subject we include in our picture, and the larger the images of objects are, while the shorter the focal length, the more subject we include in the picture and the smaller the images are.

In actual practice we must compromise between a lens which will include as large an area as possible in the field of view, and a lens which will give images as large as possible; consequently, for general all-round purposes it is best to use a lens whose focal length is somewhat greater than the longest side of the film. For 2½ x 4¼ film, for instance, we would use a lens of about 5 inches focal length.

It is most important not to use a lens of too short a focal length for the size of the film employed. There is a great temptation to do this. While a lens of 4½-inch focus as compared with a lens of 3-inch focus means a big lens in place of a little lens, and a larger shutter and a somewhat larger camera in place of a smaller shutter and an extremely compact camera; it also means (and this is vastly more important than mere camera compactness) the making of pictures having good perspective instead of pictures with bad perspective. The reason for this is that the perspective of a picture is determined by the point of view from which the lens makes the picture.

If this perspective is not pleasing to the eye it will not be pleasing in the picture.

Fig. 13 shows a picture made with a very short focus lens used close to the subject. This is a faithful rendering of the perspective that the eye saw from the viewpoint of the lens, but it is far from pleasing.

In Fig. 14 the same subject is shown photographed with a long focus lens, and in this picture the perspective is satisfactory. It likewise represents the perspective that the eye saw from the viewpoint of the lens.

We have shown that it is the working close up with a short focus lens that brings bad perspective, and that with a long focus lens we can obtain good perspective and still get the large image we desire without working close up. For instance, if you want an image two inches high in a 2¼ x 3¼ picture, and you find you must be six feet from the subject to get this image with a three-inch lens, you can get this same size of image in your picture with a 4½-inch lens at nine feet distance; and working nine feet instead of six feet from the subject means obtaining much better perspective.

Fig. 13

This is a truthful rendering of the perspective that the eye saw from the viewpoint of the short focus lens.

Fig. 14

The perspective as the eye saw it from the viewpoint of the longer focus lens.

CHAPTER III

The Apertures of Lenses

Lenses differ in the amount of light they admit, and this is very important, because the more light admitted, the shorter the exposure can be. The chief object in using a lens instead of a pinhole is to transmit more light to the film, and the amount of light that is transmitted depends upon the area of the glass in the lens.

Suppose we place a piece of cardboard, instead of a film, in the back of a camera, and have a pinhole in the card through which we can look at the lens; then point the lens toward a window; the amount of light that reaches the eye through the hole in the card depends upon how much of the light from the window is passing through the lens; that is to say, it will depend on the area of the window which we could see if there was no glass in the lens. Since the visible area of the window is bounded by the edges of the lens mount, we could see more if the lens were of shorter focal length so that the eye would be closer to it. With a lens of long focal length only a small part of the window area is visible as in Fig. 15.

With a lens of half the focal length, but of the same diameter as that shown in Fig. 15, four times as much of the window area is visible, see Fig. 16.

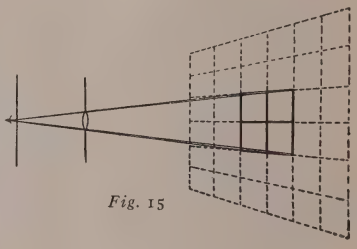


Fig. 15

This shows that the brightness of the image projected by lenses of the same diameter varies inversely as the square of the focal length of the lens. It also varies as the area of the lens surface (aperture) which admits the light. The greater the lens aperture the more light it admits. The area of the lens aperture, of course, is proportional to the square of its diameter, so that all lenses in which the diameter of the aperture bears the same ratio to

the focal length will give equally bright images. This means that the brightness of the image is determined not solely by the focal length, nor solely by the diameter of the lens aperture, but by the *relation* that exists between the lens aperture and the focal length of the lens, so that all lenses in which the diameter of the opening is, say, one-sixth of the focal length, will give equally bright images. Thus, in a lens of one-inch aperture and a focal length of six inches, the opening is one-sixth of the focal length, and in a lens of twelve inches focal length and two inches aperture, the opening is likewise one-sixth of the focal length. Both lenses are of the same *f.* value. This means that both give an image of the same brightness, and will require the same exposure. Lens "apertures" are, therefore, rated according to the ratio between their diameters and their focal lengths; thus, one in which the opening is one-sixth of the focal length is marked *f.6*; one in which the opening is one-eighth, *f.8*, and so on, and the larger the aperture, the more light the lens transmits, and the more light it transmits the shorter the exposure needed.

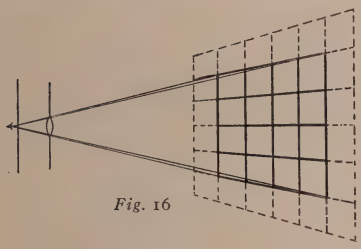


Fig. 16

But even when we have a lens with a large aperture we shall have to regard this as a reserve power for use in special circumstances, and we should not by any means use it at its largest aperture all the time.

CHAPTER IV

Depth of Focus

From the construction of a lens it follows that only the rays from a mathematical point can come together in a point again, and that the rays from any point nearer or farther than the point focused cannot meet in a point image on the film, but must produce a small disc of light instead of a sharp point of light.

The disc is termed the *circle of confusion.* If the circle of confusion is small enough we shall not be able to distinguish it from a point, and the picture will appear to be sharp.

With what are known as "fixed focus" cameras such as the Model B Vest Pocket Kodak and the box Brownies, no attempt is made to secure a wholly sharp focus for objects at all distances, but the lenses are sharply focused on the nearest point to the camera which will still enable distant objects to appear approximately sharp in the pictures, and in this way objects in the middle distance are perfectly sharp, and near objects are also sharp provided they are not too near.

The following table of these distances, beyond which everything is sharp when the largest stop is used, may be useful:

Vest Pocket Kodak (Model B)	7½ feet
No. 0 Brownie	7½ feet
No. 2 Brownie	11 feet
Nos. 2A, 2C and 3 Brownies	13 feet

If we are using a No. 2 Brownie, for instance, as long as everything is farther off than eleven (11) feet we can rely on getting a picture with everything focused sharply.

With the focusing Kodaks we must judge the distance of the object on which we wish the focus to be sharpest and set the scale to that; then we shall find that objects somewhat nearer, and also objects a good deal farther from the camera are also sharp, and the distance from the nearest to the farthest objects that appear sharp in the negative is

called the "depth of focus." This depth of focus depends on the focal length of the lens and on the size of stop used in the lens; the greater the focal length the less the depth of focus, and the *bigger the stop the less the depth of focus.* Thus in Fig. 17, we have a lens focusing near and far points at full aperture and producing large circles of confusion. In Fig. 18 a smaller stop is used in the same lens, and the circles diminish in size in proportion to reduction in the size of the stop.

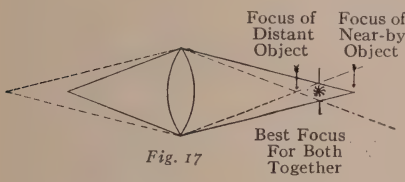


Fig. 17

Sometimes we have to focus near objects at the same time as distant ones, so that it is necessary to "stop the lens down" to some extent.

Stops are marked on two different systems, though both are based on the fundamental ratio of the diameter to the focal length of the lens. In the one system the stop is expressed simply as a fraction of the focal length; thus F./8 (commonly written *f.* 8) means that the aperture is one-eighth of the focal length of the lens; *f.*16, one-sixteenth, and so on. The rectilinear lenses that are fitted to some of the Hawk-Eye cameras are marked in the "Uniform System" (U.S.) in which the numbers are proportional to the exposure required, *f.*4 being taken as unity, so that the scale is as follows:

Fig. 18

F.	*f.*4	*f.*4.5	*f.*5.6	*f.*6.3	*f.*8	*f.*11	*f.*16	*f.*22	*f.*32	*f.*45
U.S.	1	1.26	2	2½	4	8	16	32	64	128

This table also shows the relative exposure that is required with the *f.* system stops, the exposure varying as the square of the *f.* value, so that *f.*11 requires twice the exposure of *f.*8; *f.*16 twice that of *f.*11 and so on.

In the case of the larger stops, *f.*6.3 requires about twice the exposure of *f.*4.5; and *f.*8 twice that of *f.*5.6.

CHAPTER V

The Different Kinds of Lenses

Kodak, Hawk-Eye and Brownie cameras are listed with Meniscus, Meniscus Achromatic, Kodar or Anastigmat Lenses. The Special Kodaks have Anastigmats only. The Brownies are equipped with Meniscus or Meniscus Achromatic Lenses, while with the Hawk-Eye cameras there is a choice between Meniscus, Meniscus Achromatic and Hawk-Eye lenses.

Many people do not understand the meaning of these terms, and while it is a safe rule to choose the best lens which can be afforded, certain that the better lens is worth the extra cost, it is still better to understand the properties of the different kinds of lenses and what advantages can be gained from the use of the higher grades.

The simplest lenses which can be used are made of a single piece of glass, the form of the lens being of the type which gives the best definition: that is, a meniscus or crescent shape, and the lenses are called meniscus (not meniscus achromatic) lenses. Such a meniscus lens can only be used in a fixed focus camera where the maker of the camera has put it in the correct position for forming a sharp image upon the film, but if such a lens were used in a focusing camera we should find that however carefully we focused the picture on the ground glass, the negatives would not be sharp, unless the difference between the focusing point of the visual rays by which we focus, and the chemical rays which affect the film, was provided for.

This is because a non-achromatic lens bends the rays of light of different colors to different extents, so that the yellow rays which we use for focusing do not come to a focus in the same place as the blue rays which affect the film, because the blue rays are bent more than the yellow, see Fig. 19, page 15.

In 1752, Dollond, an English optician, showed that by combining two different kinds of glass to make a lens, he

could get the blue rays to focus at the same point as the yellow rays, and lenses made in this way were called "achromatics," from the Greek words *a* meaning not, and *chroma* meaning color. The best shape of achromatic lens to use is shown in Fig. 20, and since this is also of a "meniscus" or crescent shape the lenses are called meniscus achromatics. If a single meniscus lens is used, it is necessary to "stop it down" so that only a small portion of the lens is used, because the rays which come through the edges do not focus together as well as those which come through the center, and so the image is not quite sharp if the whole lens area is used.

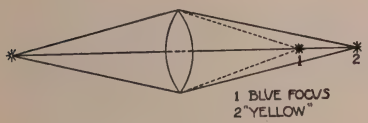


Fig. 19

This stopped-down meniscus lens has the effect of producing slight curvature of the edges of the picture, which does not matter in landscape work or portraiture; but if subjects containing straight marginal lines are photographed with such a lens, their outer lines appear slightly curved, so slightly, however, that the effect is negligible unless the image of the subject so crowds the picture area that its outer lines are very near the margins of the picture, as shown by figures 21 and 22, which represent a window sash photographed with a meniscus lens at short range.

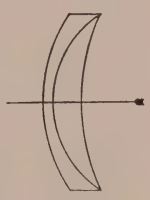


Fig. 20

If the stop is in front of the lens the curvature is in one direction, and if it is behind the lens the curvature is in the opposite direction, so that if we put two achromatics together with the stop between them, the curvature is neutralized and a lens can be made which gives no curvature at all.

The image used in photography must be formed on a flat surface but meniscus lenses tend to produce images of a saucer shape, so that it is difficult to get both the center and the edges sharp at the same time if the lenses have a large aperture. It so happens that the two kinds of glass used in an achromat must fulfill certain conditions to bring the blue and the yellow rays to the same focus, and must fulfill certain other conditions to get a picture which is flat, so that

the lenses made with "old" achromats will not give flat field images. These lenses are, therefore, said to be "astigmatic," which means that they do not give sharp-point images of points.

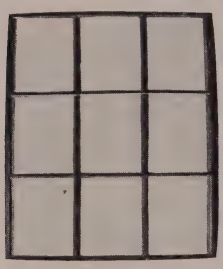


Fig. 21
Made with Stop in Front of Meniscus Lens

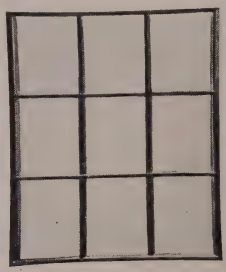


Fig. 22
Made with Stop Behind Meniscus Lens

Fig. 23
Made with Rectilinear Lens

In 1881, Professor Abbe and Otto Schott, working together at Jena, found out how to make new kinds of optical glass from which lenses could be made which would give flat field images with the blue and yellow rays at the same focus.

By the use of these new glasses the opticians have been able to make lenses that give sharp images on a flat field to the very edge of the picture and, therefore, these lenses are called "Anastigmats," meaning "not astigmatic." This better defining power can only be obtained by the most careful and skilled work in making the lens, this work being of a far higher quality than that employed on the older types of lenses, which accounts for the higher cost of anastigmats.

Recently there has been introduced a "semi-anastigmatic" type of lens known as the "Kodar," in which the general quality of the anastigmat lenses has been attained while the utmost economy of manufacture has been preserved, and these Kodar lenses have taken the place of the older "Rapid Rectilinears."

To summarize the advantages and disadvantages of the three types of lenses discussed in the preceding pages:

The single lenses (meniscus and meniscus achromatic) must be used with a relatively small stop, which means

that they are somewhat slow. They are fast enough for snapshots in good light, the shutters they are fitted with, being adjusted for the making of moderately slow "snaps." The very fact that they require a small stop gives them great depth of focus, however, and for that reason errors in focusing are largely compensated for, resulting in a high percentage of successful pictures.

The Kodar lenses have more speed than the single lenses with better general definition.

The Kodak Anastigmat, *f*.6.3, lenses are about sixty per cent. faster than the Kodar lenses and are corrected for the finest definition (sharpness). The Kodak Anastigmat *f*.5.6 is more than 25% faster than the *f*.6.3. Its popularity is based on its speed and moderate cost. The Kodak Anastigmats *f*.4.5 are almost twice as fast as the *f*.6.3's and one and one-half times as fast as the *f*.5.6. When used at their full speed—that is, with the largest opening—all large aperture lenses require accurate focusing. It should be borne in mind that both the length of focus and the stop opening affect this matter of depth of focus. That is why the 3A, the largest of the Kodaks, requires more accurate focusing than the smaller ones.

An anastigmat lens does not require any more accurate focusing than any other lens when used with the *same stop*. Take, for instance, an average landscape with a prominent object in the foreground. The correct stop would be *f*.16 and, if the sun were shining, the correct exposure 1/25 of a second. This same stop and exposure should be used with a single lens, a Kodar or an anastigmat, and the depth of focus with the same focal length of lens would be the same in all cases—no more accurate focusing would be required with one lens than with another.

The lens equipment which an amateur should buy depends entirely upon what he can afford and what he wants to do with his camera. If snapshots in bright sunlight of landscapes, groups or individuals are all that the camerist will want to take, any of the types mentioned will prove entirely satisfactory. But many who buy cameras know that they will want to take pictures on dull days or in the later hours after work, pictures of rapidly moving objects

and of vivacious youngsters indoors where a reasonably high shutter speed is required to arrest unlooked for movement and where the large aperture lens would help to prevent under-exposure. Most people want to take some of these pictures sooner or later. On these occasions the speed of the Anastigmat is very desirable, and with Kodak or Graflex cameras equipped with Anastigmats working at *f*.6.3, *f*.5.6 or *f*.4.5 there is a lens for every purse. The *smaller* the *f*. number the *larger* the aperture, and with it the more different and the more difficult types of photography can be attempted.

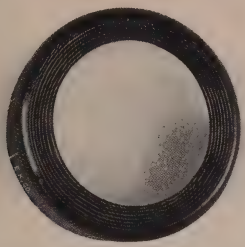
When the light is weak and an anastigmat is used at its full opening, or nearly its full opening, in order to get a well-timed snapshot, there will be a gain in speed but a loss in *depth* of focus. The object at the focused distance may photograph even sharper than it would with the single lenses, but objects a little nearer the camera or a little farther away will not be so sharp because depth of focus has been sacrificed for speed. And, of course, this same thing is true in using a large stop in order to use a sufficiently short exposure to arrest the motion of moving objects. With a fixed focus camera working at a fixed shutter speed, all still objects, about fifty feet away, would be sharp and, with a good light, fully timed, but rapidly moving objects might show a blur. With an anastigmat lens opened to *f*.4.5, *f*.5.6 or *f*.6.3 and a shutter speed of 1/200, 1/150 or 1/100 of a second, it is possible to arrest fast motion and get a fully timed negative (with good light), but in such case the camera must be focused accurately.

The Kodak Portrait Attachment

The Portrait Attachment is a supplementary single meniscus lens which is intended to shorten the effective focus of the lens in front of which it is placed, so as to make it possible to focus objects at a short distance without too great an extension of the camera bellows.

With the average Kodak the extension of bellows will not permit subjects to be focused which are nearer than six feet, while with the box Brownies, which have no focusing

attachment, photographs will not be sharp of subjects nearer than those already given on page 12, unless the Portrait Attachment is used. The Portrait Attachment therefore enables one to place the camera nearer the subject, and thus obtain larger, sharply focused images than would



The Kodak Portrait Attachment

otherwise be possible. It is especially adapted for making portraits, photographing flowers and other objects at short range, but is not intended for photographing landscapes or any distant objects.

The Diffusion Disk

Designed for diffused or soft-focus effects, this disk slips in front of the regular lens exactly as does the Portrait Attachment. Upon its surface shallow circular grooves are polished with the utmost precision. The depth and spacing of these lines have been computed with mathematical accuracy to produce a negative with the proper soft-focus effect. The use of the Diffusion Disk does not change the necessary exposure. It is made in two styles, the Kodak Diffusion Portrait Attachment and the Kodak Pictorial Diffusion Disk. The Diffusion Portrait Attachment is a Portrait Attachment upon which have been polished these light-diffusing grooves. The Pictorial Diffusion Disk does not alter the focus of the lens.

CHAPTER VI

Ciné-Kodak and Kodascope Lenses

The introduction of the Ciné-Kodaks and Kodascopes called for the design of photographic lenses which were different in one important respect from any previous Kodak lenses—they were of much shorter focal length. A short focus lens can have a larger stop opening than a long focus lens and still retain sufficient depth of focus. Of course, the tiny image of the Ciné-Kodak—less than half an inch across—must be focused more sharply than is necessary for the bigger images used in ordinary cameras, but nevertheless the Ciné-Kodak lenses could be made to work at much larger *f.* values than ordinary camera lenses.

The Model A, Ciné-Kodak was fitted with an anastigmat working at *f.*3.5, and this was focused by a precision focusing mechanism which moved the lens through distances as small as one-thousandth of an inch with the utmost accuracy. When the Ciné-Kodak, Model B, was introduced, an *f.*6.5 anastigmat was fitted in order to eliminate the focusing problem for the user, and this was followed by an *f.*3.5 model in which, instead of moving the lens to focus it, a portrait attachment is inserted, the depth of focus without the portrait attachment being sufficient for pictures at any distance beyond 5 feet, while with the portrait attachment objects from 5 to 2 feet are sharp.

The latest lens for the Ciné-Kodak is a real triumph of the lens maker's art. It works at the enormous aperture of *f.*1.9, admitting nearly four and one-half times as much light as a lens working at *f.*4, which has been taken as the standard maximum aperture in this book, and more than three times as much light as its *f.*3.5 predecessor. This lens involved a redesign of the camera to give it the accuracy necessary to maintain the film to the hair's breadth position required for sharp focus, while the lens itself is mounted in a focusing jacket of the utmost precision. For all openings of the diaphragm, from *f.*5.6 to *f.*16 the Ciné-Kodak equipped with the *f.*1.9 lens may be employed as a fixed focus camera by setting the focusing scale at 25 feet, under which conditions subjects 8 feet from the camera and farther will be sharp.

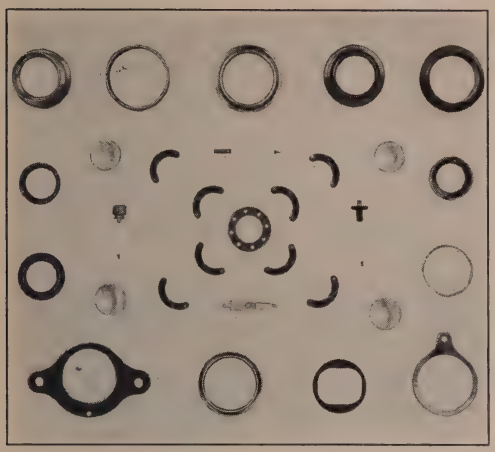


Fig. 24

When the lens is used at greater openings in dull light or for work indoors, for which it is particularly designed, or at shorter distances than 8ft., it is necessary to focus the lens by the means provided.

The lenses fitted to the Kodascopes are also of a very interesting type. They work at a relative aperture of *f*.2 and are about an inch across, thus giving the maximum illumination on the screen, while at the same time they cut sharply to the edges of the picture.

There were many problems involved in the design and construction of the tiny Ciné-Kodak lenses. The illustration (Fig. 24) will give an idea of the small size and delicacy of the parts involved. They are manufactured and assembled by the same methods as those used in making lenses for microscopes. The range of lenses made by the Kodak Company extends from these microscopic lenses, difficult to handle because of their small size and large aperture, to the immense lenses required by the Air Service of the United States Army, with which the aviators propose to spy on their enemies when their cameras are suspended four miles up in the air, see Fig. 25.

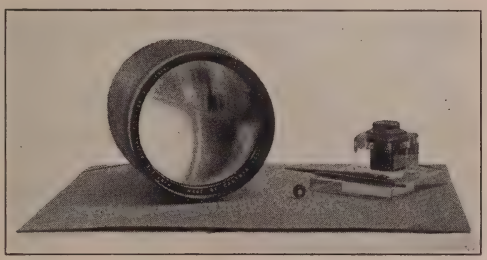


Fig. 25

CHAPTER VII
Cost and Quality in Anastigmats

A scientific tool is more accurate than a skilled hand and a practiced eye.

Realizing that because of the superior results they produce, a more general use of anastigmat lenses would be of an immense advantage in amateur photography, we began their manufacture in 1911.

There were already several good anastigmats on the market but they were priced so high that their use was not general. Our problem was to produce a lens that would be the equal of the best of these and produce it at a price that would be within the reach of every Kodak customer.

Lenses Ready for Fine Grinding are mounted on metal tools with pitch, into which they are pressed while it is hot.

We had a market ready made. Our camera factories were to be the customers of our lens factory. Selling cost would thereby be eliminated. We would make lenses not for general use—not merely for "cameras"—but lenses that would be made for a specific purpose—to use with a certain shutter on a certain size of Kodak or Graflex. With these advantages and with quantity production made possible through a more extensive use of specialized machinery than had heretofore been practical, we would, we believed, be able to reach our ideals.

The results have justified the plan.

Through our technical staff and our intimate acquaintance with every phase of photography at home and abroad,

we were able to get at the fundamentals. We knew where to put our hands on the men. We were able, through our experts, including a staff of men who are unexcelled anywhere in the world in optical mathematics, to work out the formulae with the utmost exactness.

In our Research Laboratories we were able to test with the utmost accuracy the refractive power of the various glasses to be used. We designed and built the instruments

Grinding and Polishing Kodak Anastigmats are slow processes. Rapid motion would cause an increase in temperature, which might change the shape of the wax mold that does the polishing. And to permit an infinitesimal variation in the curvature of the lens would be to compromise its quality as an anastigmat.

of precision that were to make the lenses. We designed and built a testing bench of such exactness that, during the war, the Government used it for testing all of its aerial lenses. We made haste slowly—always with the idea in mind that the Kodak Anastigmats must produce negatives of critical sharpness—and that the equipment for their manufacture must be so complete that perfect lenses could be turned out at a minimum cost.

We poured dollars ungrudgingly into the perfecting of dies and tools and measuring devices in order that still more

dollars might be saved in the making of the lenses themselves. Nothing that could be well done by machinery was left to be done by hand. The quality of the Kodak Anastigmats has again proved that a scientific tool is more accurate than a skilled hand and a practiced eye.

Testing the Surface of a Kodak Anastigmat with the master glass. The interference of light rays causes arcs of color, known as Newton Rings, when the test glass is slipped over the lens. The fewer the Newton Rings the closer the lens is to perfection.

The fact that the Kodak Anastigmats so fully met the exacting requirements of the air service during the war, where speed combined with the utmost exactness was an essential, caused them to be adopted by the War Department. These lenses are made in larger sizes, of course, *but on the Kodak Anastigmat formulae.* In the smaller sizes, made by the same expert workmen, under the same superintendence and tested in the same exacting manner, they are now making Kodak history.

For use on Kodaks, the outstanding advantage of *all* of the Kodak Anastigmats is apparent when it comes to making large prints from small negatives. Because of the fine definition (sharpness) of negatives made with Kodak Anastigmats they make excellent enlargements. The Kodak Anastigmats *f*.6.3, *f*.5.6 and *f*.4.5 enable the camerist to make snapshots on dark days, and to make snapshots successfully on bright days with a speed of 1/200, 1/150 or 1/100 of a second, which means that rapidly moving objects that are not too close can be caught by the Kodak. With the larger openings, snapshots can be made of portraits in the

shade of a tree, or on a porch, and even indoors when the lighting conditions are favorable.

The Kodak Anastigmat *f*.4.5 is also used on the Graflex with its focal plane shutter, having a speed of 1/1000 part of a second—fast enough to "stop" a racing automobile or catch a humming bird on the wing.

The Lens Bench is the supreme tests of optics. The action of a light ray as it passes through the Kodak Anastigmat is observed by looking through the finished lens at a point source of illumination seventy feet distant.

The Kodak Anastigmats lack nothing in speed, definition and flatness of field. For the hand camerist they have the advantage of being made for a specific purpose—and they fit that purpose.

Because the formulae on which they are based are fundamentally right, because of the scientific exactness at every stage of their manufacture, because of the exacting tests and the inspections made with jealous care, Kodak Anastigmats uniformly produce negatives of a quality that has placed them in the front rank in the anastigmat field.

In lens making, just as in every other important phase of photography, the Eastman Kodak Company has, through its policy of getting at the fundamentals, become the leader. From the mathematical formulae, through every stage of their development and manufacture, the Kodak Anastigmats are right.

They are products that have proved that we, here in America, can equal the world in scientific production when we really put our minds to it.

Depth of Focus Tables

Depth of focus, as stated in Chapter IV, is the distance from the nearest to the farthest objects that appear sharp in the negative or print. The depth of focus of any lens depends upon the relation between the focal length of the lens and the size of the stop or diaphragm used.

In the tables on the following pages illustrations are given of how depth of focus or range of sharpness varies with lenses of different focal lengths. This variation for any particular Kodak lens is given in the manual which accompanies the Kodak.

Table No. I

Anastigmat and Kodar *f*/6.3 Rapid Rectilinear —— Meniscus Achromatic ——	*f*/7.7, 7.9 & 8 U.S. 4 ——	*f*/11 U.S. 8 No. 1	*f*/16 U.S. 16 No. 2	*f*/22 U.S. 32 No. 3	*f*/32 U.S. 64 No. 4	*f*/45 U.S. 128 ——
Distance Focused Upon						
100 ft.	55 to inf.	49 to inf.	40 to inf.	32 to inf.	25 to inf.	20 to inf.	15 to inf.
50 ft.	35 to 82 ft.	33 to 105 ft.	29 to inf.	24 to inf.	20 to inf.	17 to inf.	13 to inf.
25 ft.	21 to 31 ft.	20 to 34 ft.	19 to 40 ft.	17 to 52 ft.	15 to 93 ft.	12 to inf.	10 to inf.
15 ft.	13½ to 17 ft.	13 to 18 ft.	12 to 19 ft.	11 to 21 ft.	10 to 26 ft.	9 to 38 ft.	8 to 112 ft.
12 ft.	10¾ to 13 ft.	10½ to 13½ ft.	10¼ to 14½ ft.	9¾ to 16 ft.	9 to 18 ft.	8 to 23 ft.	7½ to 37 ft.
10 ft.	9½ to 10¾ ft.	9¼ to 11 ft.	9 to 11⅓ ft.	8½ to 12 ft.	8 to 14 ft.	7½ to 17 ft.	7 to 22 ft.
8 ft.	7¾ to 8⅓ ft.	7½ to 8½ ft.	7¼ to 9 ft.	7 to 9½ ft.	6⅔ to 10 ft.	6¼ to 11⅓ ft.	5¾ to 14 ft.
6 ft.	5⅚ to 6⅙ ft.	5¾ to 6¼ ft.	5⅔ to 6½ ft.	5½ to 6¾ ft.	5¼ to 7 ft.	5 to 7¾ ft.	4¾ to 8¾ ft.

"Inf." is the abbreviation for Infinity—meaning an unlimited distance from the lens.

The above table applies in a general way to all cameras making pictures 3¼ x 5½, but owing to variations in the focal length of the different lenses that are fitted to certain models, the accurate and complete figures for each camera will be found in the manual that accompanies it.

Table No. II

Anastigmat and Kodar	*f*/4.5	*f*/5.6	*f*/6.3	*f*/7.7,7.9 & 8	*f*/11	*f*/16	*f*/22	*f*/32	*f*/45
Rapid Rectilinear	——	——	——	U.S. 4	U.S. 8	U.S. 16	U.S. 32	U.S. 64	U.S. 128
Meniscus Achromatic	——	——	——	——	No. 1	No. 2	No. 3	No. 4	——

Distance Focused Upon	Ft. Ft.	Ft. Ft.	Ft. Ft.	Ft. Ft.	Ft. Ft.	Ft. Ft.	Ft. Ft.	Ft. Ft.	Ft. Ft.
100 ft.	50 to inf.	44 to inf.	42 to inf.	35 to inf.	28 to inf.	21 to inf.	17 to inf.	12 to inf.	9 to inf.
25 ft.	20 to 34	19 to 37	18 to 40	$17\frac{1}{2}$ to 46	$15\frac{1}{2}$ to 68	$13\frac{1}{2}$ to inf.	11 to inf.	9 to inf.	$7\frac{1}{2}$ to inf.
15 ft.	13 to $17\frac{3}{4}$	$12\frac{1}{2}$ to $18\frac{1}{2}$	$12\frac{1}{3}$ to 19	$11\frac{3}{4}$ to $20\frac{1}{2}$	$10\frac{3}{4}$ to 24	$9\frac{1}{2}$ to 34	$8\frac{1}{3}$ to 71	7 to inf.	6 to inf.
10 ft.	$9\frac{1}{2}$ to 11	9 to $11\frac{1}{2}$	$8\frac{3}{4}$ to $11\frac{3}{4}$	$8\frac{1}{2}$ to 12	8 to 13	$7\frac{1}{2}$ to 15	7 to 20	6 to 32	5 to inf.
8 ft.	$7\frac{1}{2}$ to $8\frac{3}{4}$	$7\frac{1}{3}$ to 9	$7\frac{1}{4}$ to $9\frac{1}{4}$	7 to $9\frac{1}{2}$	$6\frac{3}{4}$ to 10	$6\frac{1}{4}$ to $11\frac{1}{2}$	$5\frac{3}{4}$ to 14	5 to 21	$4\frac{1}{2}$ to 66
6 ft.	$5\frac{3}{4}$ to $6\frac{1}{3}$	$5\frac{2}{3}$ to $6\frac{1}{2}$	$5\frac{1}{2}$ to $6\frac{3}{4}$	$5\frac{1}{3}$ to $6\frac{5}{6}$	$5\frac{1}{4}$ to 7	5 to $7\frac{1}{2}$	$4\frac{3}{4}$ to 10	$4\frac{1}{2}$ to 10	4 to 14

"Inf." is the abbreviation for Infinity—meaning an unlimited distance from the lens.

The above table applies in a general way to all cameras making pictures $2\frac{1}{2}$ x $4\frac{1}{4}$ or $3\frac{1}{4}$ x $4\frac{1}{4}$, but owing to variations in the focal length of the different lenses that are fitted to certain models, the accurate and complete figures for each camera will be found in the manual that accompanies it.

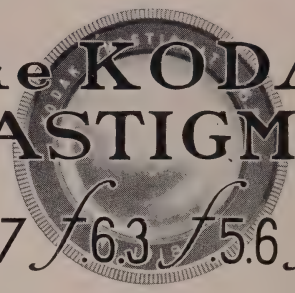
Table No. III

Anastigmat and Kodar	*f*/4.5	*f*/5.6	*f*/6.3	*f*/7.7,7.9 & 8	*f*/11	*f*/16	*f*/22	*f*/32
Rapid Rectilinear	——	——	——	——	U.S. 8	U.S. 16	U.S. 32	
Meniscus	——	——	——	——	No. 1	No. 2	No. 3	No. 4
Distance Focused Upon	Ft. Ft.	Ft. Ft.	Ft. Ft.	Ft. Ft.	Ft. Ft.	Ft. Ft.	Ft. Ft.	Ft. Ft.
100 ft.	30 to inf.	25 to inf.	23 to inf.	19 to inf.	15 to inf.	11 to inf.	8 to inf.	6 to inf.
25 ft.	16 to 60	14½ to 90	13¾ to 139	12½ to inf.	10½ to inf.	8 to inf.	6½ to inf.	5 to inf.
10 ft.	8 to 13	7¾ to 14	7½ to 15	7 to 17	6½ to 23	5½ to 60	4¾ to inf.	3¾ to inf.
6 ft.	5⅓ to 7	5⅙ to 7⅓	5 to 7⅔	4¾ to 8	4½ to 9	4 to 12½	3½ to 21	3 to inf.

"Inf." is the abbreviation for Infinity—meaning an unlimited distance from the lens.

The above table applies in a general way to all cameras making pictures 1⅝ x 2½, but owing to variations in the focal length of the different lenses that are fitted to certain models, the accurate and complete figures for each camera will be found in the manual that accompanies it.

The KODAK ANASTIGMATS



f.7.7 *f*.6.3 *f*.5.6 *f*.4.5

Lens Achievement

The production of Kodak Anastigmat lenses is a distinct achievement. Not only are they at least the equal of the finest anastigmats made anywhere in the whole world, but also through the use of scientific, specialized machinery of the utmost accuracy, they are made and sold at a price which brings anastigmat advantages to hundreds of thousands of amateurs who have not hitherto felt that they could afford a lens of the finest quality.

Eastman Kodak Company

Rochester, N. Y.